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INFILTRATION CHARACTERISTICS OF SOILS AT APPLE VALLEY, MINNESOT--ETC(U)

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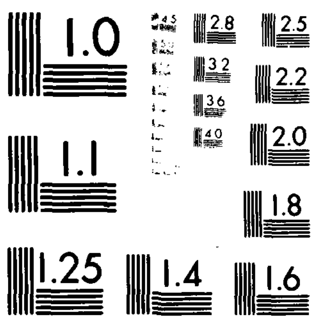

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Special Report 80-36

October 1980

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INFILTRATION CHARACTERISTICS OF SOILS AT APPLE VALLEY, MINN.; CLARENCE CANNON DAM, MO.; AND DEER CREEK LAKE, OHIO, LAND TREATMENT SITES

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By

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Large-scale, 3- to 6-m diameter infiltration tests provide realistic data for determining soil infiltration rates. Tensiometers can be used to monitor the relative degree of saturation during the test. At Apple Valley, Minnesota, the saturated infiltration rate is moderately rapid, at Clarence Cannon Dam, Missouri, the rates range from moderate to slow, and at Deer Creek Lake, Ohio, from moderately slow to slow.

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PREFACE

This study was conducted by Dr. Harlan L. McKim, Soils Scientist, Bruce E. Brockett, Physical Science Technician, Earth Sciences Branch, Research Division, Gunars Abele, Research Civil Engineer, Applied Research Branch, and Jonathan Ingersoll, Civil Engineering Technician, Geotechnical Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

This work was performed during 1979 for the U.S. Army Engineer District, Huntington, W.V., under Intra-Army Order No. E8679ED-03, "Deer Creek Land Treatment System"; and for the U.S. Army Engineer Division, New England under No. 79-C-3, "Development of Optimum Automated Procedures for Planning, Design and Management of Land Treatment," CWIS 31633.

During the field tests, assistance was received from the personnel of the U.S. Department of Agriculture, University of Minnesota; U.S. Army Corps of Engineers, St. Louis District; and U.S. Army Corps of Engineers, Deer Creek Office, Huntington District.

This report was technically reviewed by John Bouzoun, James C. Martel and Carolyn Merry, CRREL, and by Dr. Satish C. Gupta and Mr. Dennis Linden, U.S. Department of Agriculture, University of Minnesota.

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NOMENCLATURE

Y = Cumulative intake (cm)

ΔY = Incremental intake (cm)

t = Time (hr)

Δt = Incremental time (hr)

I = Infiltration rate (cm hr^{-1})

A, C = Intercepts

b, n = Slope of line

z = Depth (cm)

γ = Dry density of soil (g cm^{-3})

w = Gravimetric water content (%)

V_w = Volumetric water content (%)

V_s = Volume of solids (%)

h = Soil moisture tension (cm of water)

INTRODUCTION

During August 1979, field infiltration tests were conducted at three land treatment sites: Apple Valley, Minnesota; sites 11 and 12, Clarence Cannon Dam, Missouri; and Deer Creek Lake, Ohio. The principal objective of the tests was to evaluate the feasibility of a large-scale, in situ infiltration test method for determining the infiltration rate of various soils. The study also included an evaluation of the installation and operation of the test equipment and instrumentation, as well as the data collection schedule and analysis techniques.

TEST PROCEDURE

The tests were conducted using a 6.1-m (20-ft) diameter area with a seal around the periphery to prevent surface runoff (Fig. 1). Aluminum flashing, 35 cm wide, was installed in a 15 cm deep, precut groove, leaving a 20-cm high wall around the test area. Tensiometers were installed 30 cm apart in three radial rows at five or six different depths (that is, a total of three tensiometers at each depth). Soil tension data were obtained from periodic tensiometer readings and soil water content data from cores obtained prior to and at various times after water application. Cumulative intake data were obtained from periodic monitoring of head drop, read from graduated scales on the inside of the aluminum berm. Water was applied at a rate of approximately 0.5 to 1 cm min^{-1}.

At site 11, Clarence Cannon Dam, a 3-m (10-ft) diameter area was used, and the tensiometers were installed in a 1-m diameter circle, one tensiometer for each depth (Fig. 2).

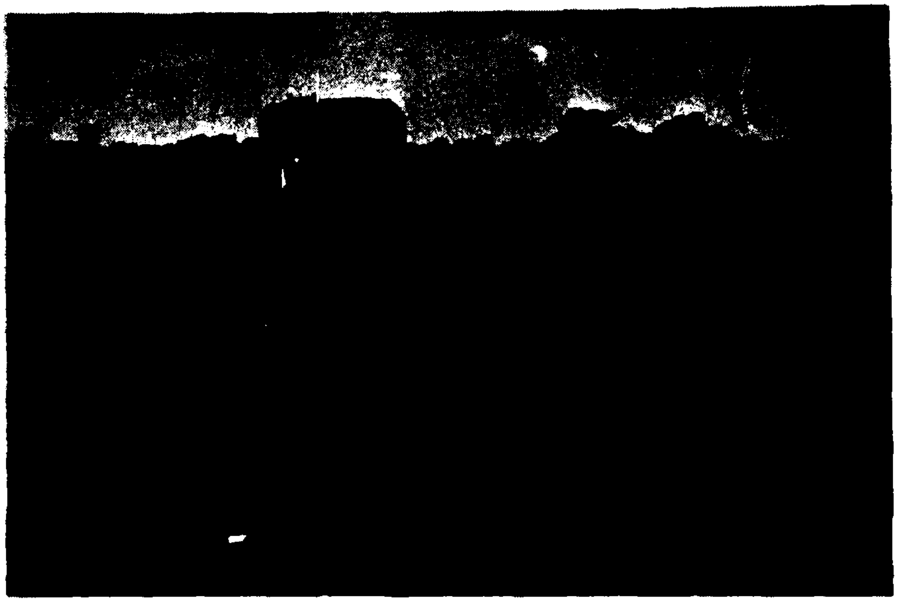


Figure 1. Infiltration test layout (6.1-m diameter).

Figure 2. Infiltration test layout (3-m diameter).

One of the important parameters in the design of land treatment systems is the infiltration rate for a saturated soil condition, which is equivalent to the effective saturated permeability; so it was first necessary to apply water until the soil in the test area became saturated. Infiltration data were also obtained during these initial water applications to compare the infiltration rate for unsaturated soil with that for saturated soil.

The test procedure is discussed in detail in U.S. Army Corps of Engineers ETL (in press).

DISCUSSION OF RESULTS

General discussion

The infiltration rate I can be determined by three methods:

1. The incremental infiltration rates can be computed from the incremental intake ΔY and time Δt data (Fig. 3a):

$$I = \frac{\Delta Y}{\Delta t}$$

The computed incremental I values can then be plotted vs time on a log-log plot (open circles in Fig. 3b) and the expression for I determined from the best fit line:

$$I = At^{-b}$$

This procedure usually results in a considerable data scatter, unless the Y vs t data follow a very smooth line.

2. The Y vs t data can be plotted on an arithmetic scale plot, a best fit smooth curve drawn through the data points, and the I values determined by measuring the slope of the tangent to the curve at any convenient or desired t (Fig. 3c). The scaled I values are then plotted vs t on a log-log plot, and the expression for I determined as in the previous method. This procedure results in less data scatter (solid circles in Fig. 3b), since the I data are values interpolated from a smooth curve.

3. The Y vs t data can be plotted on a log-log plot and, if a straight line can be drawn through the points (Fig. 3d), the expression for Y is determined by

$$Y = Ct^n$$

Since $I = \frac{dY}{dt}$, I can be derived

$$I = Cnt^{n-1}$$

This method is probably the most reliable for expressing the infiltration rate as a function of time and is commonly used. Also, in this case the cumulative intake Y and infiltration rate I are mathematically compatible.

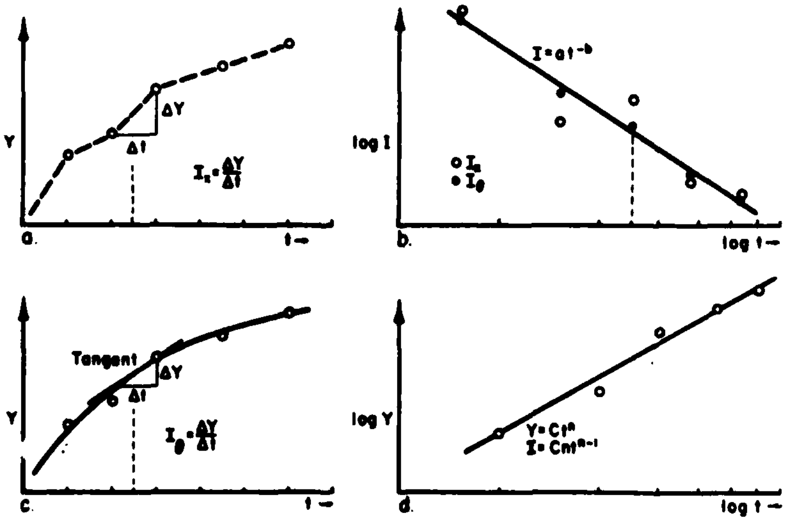


Figure 3. Methods for computing infiltration rate.

If Y vs t data yield a straight line on an arithmetic plot, the infiltration rate is, of course, constant and results in a horizontal line on a log I vs log t plot (I = Ct).

Sometimes the log Y vs log t data indicate a break in the rate and cannot be represented by a single straight line.

Apple Valley site

The site preparation required approximately 2 hr for four people. The berm installation was a 3 to 4 man-hour effort, the tensiometer installation required 2 man-hours, obtaining cores for soil profile description took 1 man-hour, and approximately 1 man-hour was spent on miscellaneous tasks. Obtaining soil samples to determine density profiles, which involved digging a small pit adjacent to the test site after the test, required 1.5 hr for two people.

Figures 4-9 show various stages of the site preparation and the infiltration test.

The soil profile characteristics at this site are described below:

0-15 cm: black, friable silt loam, fine, granular, many roots
15-30 cm: fine silt, subangular blocking, brown mottles, dark brown to black matrix, roots common
30-45 cm: light brown silt, few roots
45-60 cm: silt, subangular blocking, very few roots
60-75 cm: sandy soil

The first application of 7.3 cm of water was not sufficient to achieve a saturated condition (Table 1). The second application, also 7.3 cm of water, resulted in saturation after 0.5 hr. The third (saturated) application, 6.2 cm of water, was done at this time.

Figure 4. Perimeter groove cutting.

Figure 5. Berm installation.

Figure 6. Sealing berm.

Figure 7. Water application.

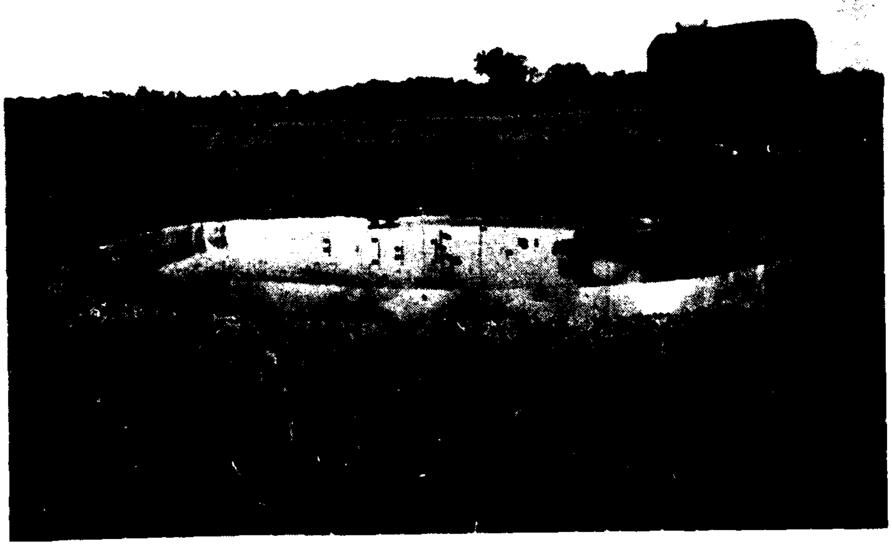


Figure 8. After water application.

Figure 9. Monitoring soil tension.

The soil tension data (Table 1), are plotted in Figures 10 (first application) and 11 (saturated, third application).

The dry density, gravimetric and volumetric data (Table 2) are plotted in Figures 12 and 13. For clarity, the water content data for 2.5 and 4.5 hr after the third (saturated) application are not shown. The 1- and 2-day data are mean values of the measurements obtained during the forenoon (1 core) and again in the afternoon (1 core) of each day.

The one puzzling feature of the water content profiles is the apparent increase in water content between 1 and 2 days after the application. Although the increase is small (1-2%), it occurs at all depths (Fig. 12 and 13). The trend of increasing tension values (drying) for the 2-day period after application does not indicate anything unusual (Fig. 11), and therefore, does not support the observed soil water content increase.

Since the water content data were obtained by the same personnel using the same technique, the effect of measurement procedures can be discounted when trying to explain why the field data, in this case, imply what appear to be contradictions between the expected and observed amount or movement of water in the soil. It is more likely that the soil profile characteristics in a 25-m^2 test area are not sufficiently uniform to be accurately described by only one or two soil cores. Therefore, if one core is taken a couple of meters from another the water content data from the one core may not duplicate the water content data from the other, and neither core may be representative or typical of the entire test area. Also, if the water content data are not obtained adjacent to each tensiometer, the water content and soil tension data may not correlate. In other words, the sample number has to be increased to obtain more reliable data. (For a discussion of the effect of the variability of soil water content data on water budget calculations, refer to Abele et al. 1979.)

Table 1. Soil tension (Apple Valley).

Depth (cm):	8	25	43	61	76	97
Time	Tension (cm of water)					
0	250	590	710	580	305	40
	1st application = 7.3 cm					
1 min	0	430	690	580	285	40
3 min	0	85	685	575	280	45
4 min	0	15	645	585	280	45
6 min	0	5	375	585	285	50
8 min	0	0	55	585	285	50
11 min	0	0	25	570	285	50
14 min	0	0	20	535	285	45
20 min	5	0	15	400	285	50
25 min	10	5	10	305	285	45
30 min	10	5	10	270	285	45
40 min	10	10	10	290	285	40
50 min	15	5	10	305	275	40
60 min	15	10	10	325	255	40
1.25 hr	15	15	15	340	240	40
1.5 hr	20	15	15	350	230	35
18 hr	40	60	50	120	120	35
	2nd application = 7.3 cm					
0.5 hr	0	0	0	0	5	30
	3rd application = 6.2 cm					
0.4 hr	0	0	0	0	5	10
2.4 hr	10	20	20	20	30	20
3.4 hr	20	25	20	20	30	25
4.4 hr	20	25	20	20	30	25
1 day	40	50	35	30	30	30
2 days	60	65	50	40	35	30

Tension data represent mean of 3 observations.

Table 2. Volumetric composition of soil (Apple Valley).

Depth z (cm)	Density γ (g cm^{-3})	Gravimetric w (%)	Volumetric V_w (%)	Volumetric V_s (%) (G_s = 2.65)	Volumetric $V_w + V_s$ (%)
		Water Content			
		Before 1st application (1500 hrs, 13 Aug):			
8	1.19	29.9	35.6	45.0	80.6
25	1.21	21.2	25.6	45.7	71.3
43	1.21	16.3	19.7	45.7	65.4
61	1.52	13.1	19.8	57.2	77.0
76	1.65	8.7	14.4	62.2	76.6
		1st application = 7.3 cm (1530 hrs, 13 Aug)			
		Before 2nd application (0930 hrs, 14 Aug):			
8		29.4	35.1	45.0	80.1
25		29.1	35.2	45.7	80.9
43		27.4	33.3	45.7	79.0
61		20.0	30.3	57.2	87.5
76		-	-	62.2	-
		2nd application = 7.3 cm (1000 hrs, 14 Aug)			
		3rd application = 6.2 cm (1030 hrs, 14 Aug)			
		1 hr after 3rd application			
8		34.9	41.6	45.0	86.6
25		32.1	38.8	45.7	84.5
43		30.4	36.8	45.7	82.5
61		26.2	39.8	57.2	97.0
71	~ 1.6	21.0	34.6	60.4	95.0
84	~ 1.7	8.6	14.2	64.2	78.4
		After 2.5 hrs			
8		34.5	41.2	45.0	86.2
25		29.0	35.0	45.7	80.7
43		28.2	34.2	45.7	79.9
61		24.1	36.6	57.2	93.8
76		16.9	27.9	62.2	90.1

Table 2. (cont'd).

Depth z (cm)	Density γ (g cm^{-3})	Gravimetric w (%) Water Content	Volumetric V_w (%)	Volumetric V_s (%) (G_s = 2.65)	Volumetric $V_w + V_s$ (%)
		After 4.5 hrs			
8	1.19	33.9	40.5	45.0	85.5
25	1.21	30.0	36.2	45.7	81.9
43	1.21	29.4	35.6	45.7	81.3
61	1.52	22.6	34.2	57.2	91.4
76	1.65	21.2	34.9	62.2	97.1
		After 1 day *			
8		31.4	37.4	45.0	82.4
25		27.8	33.6	45.7	79.3
43		27.2	32.9	45.7	78.6
61		22.4	34.1	57.2	91.3
76		11.3	18.6	62.2	80.8
		After 2 days *			
8		31.6	37.7	45.0	82.7
25		29.1	35.1	45.7	80.8
43		27.8	33.7	45.7	79.4
61		24.1	36.5	57.2	93.7
76		11.9	19.6	62.2	81.8

* One and two day data represent mean of 2 samples.

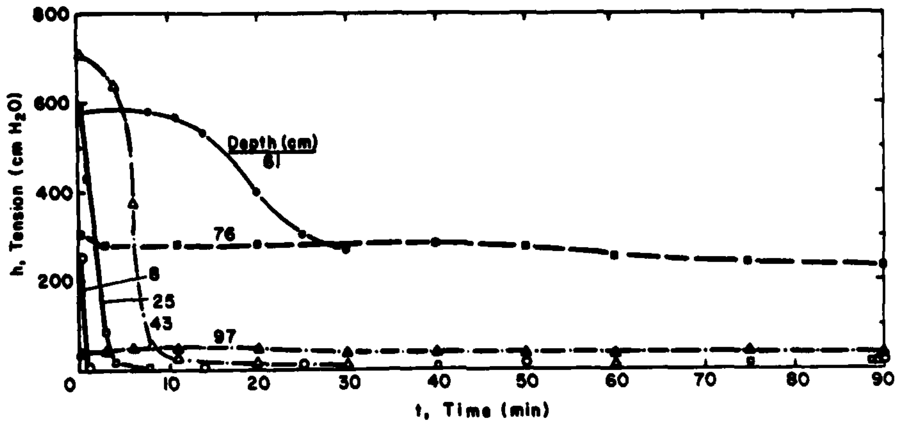


Figure 10. Soil tension vs time at various depths (unsaturated) (Apple Valley).

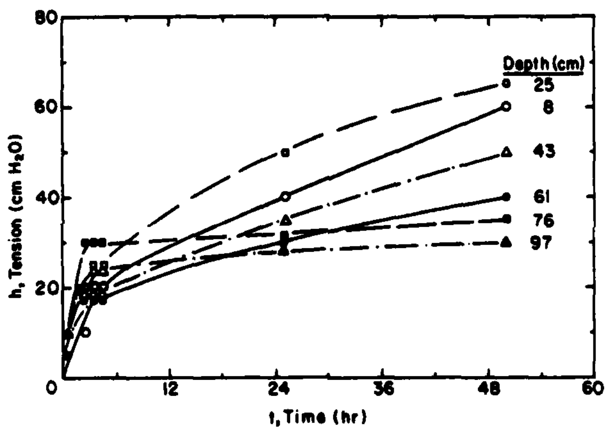


Figure 11. Soil tension vs time at various depths (saturated) (Apple Valley).

The cumulative intake Y vs time t data for the first (unsaturated) and third (saturated) applications are listed in Table 3 and plotted in Figure 14 on arithmetic scales. Figure 15 shows the same data on a log-log plot.

For the unsaturated condition, the rate of infiltration is constant (Y vs t is a straight line on an arithmetic plot, or slope $n = 1$ on a log-log plot).

For the saturated condition, the rate I is nearly constant; there is a slight break in the arithmetic Y vs t plot at $t \approx 0.5$ hr. The slope of the best fit line on a log-log plot is 0.93.

The expressions for the cumulative intake (from Fig. 15) and the computed rate of infiltration are:

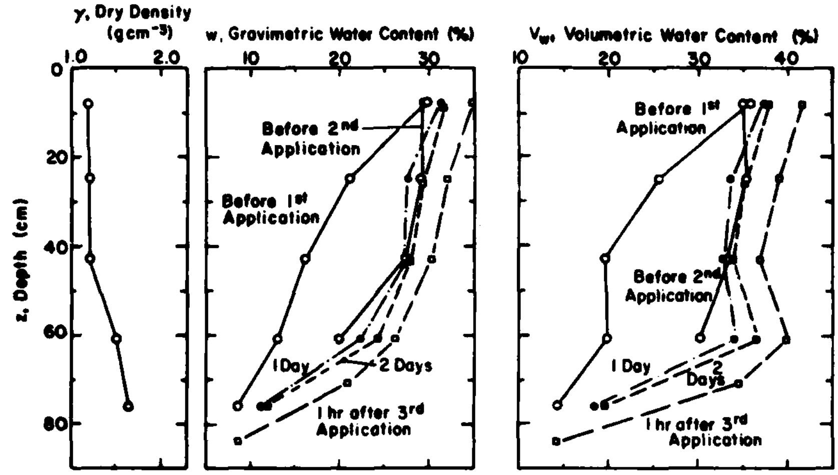


Figure 12. Soil density and water content vs depth (Apple Valley).

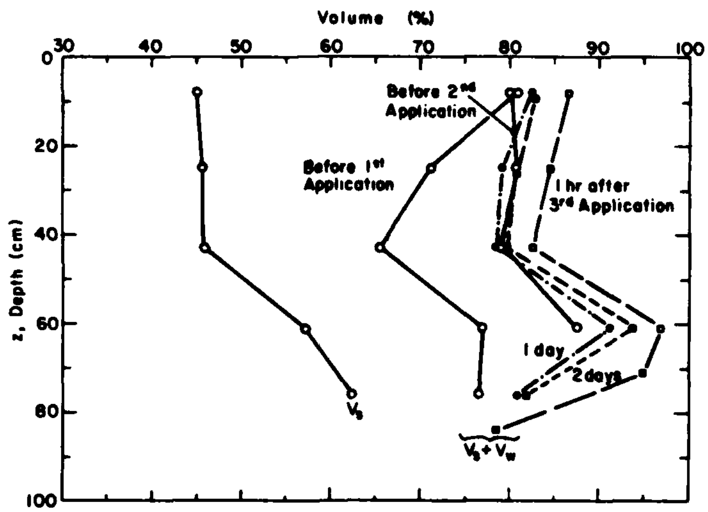


Figure 13. Volumetric composition of soil (Apple Valley).

Unsaturated condition

$$Y = 23\ t\ (\text{cm}) \qquad (t = \text{hr})$$

$$\text{or}\quad Y = 9.1\ t\ (\text{in.})$$

$$I = 23\ (\text{cm hr}^{-1})$$

$$\text{or}\quad I = 9.1\ (\text{in. hr}^{-1})$$

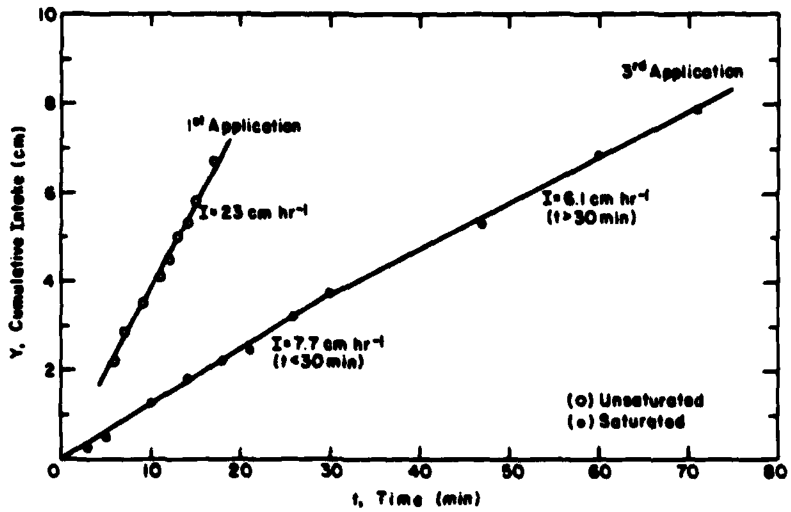


Figure 14. Cumulative intake vs time (Apple Valley).

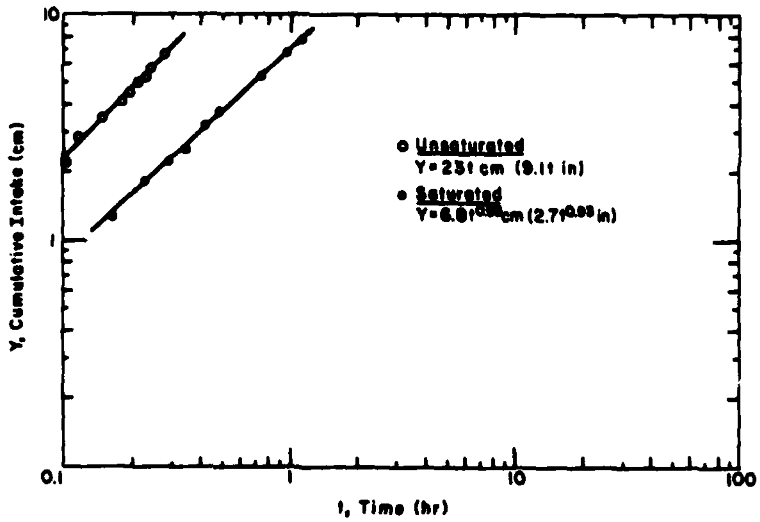


Figure 15. Cumulative intake vs time (log-log) (Apple Valley).

Saturated condition

$$Y = 6.8\ t^{0.93}\ (\text{cm})$$

$$\text{or}\quad Y = 2.7\ t^{0.93}\ (\text{in.})$$

$$I = 6.3\ t^{-0.07}\ (\text{cm hr}^{-1})$$

$$\text{or}\quad I = 2.5\ t^{-0.07}\ (\text{in. hr}^{-1})$$

Table 3. Cumulative intake (Apple Valley).

1st Application (Unsaturated)		3rd Application (Saturated)	
Time (min)	Y (cm)	Time (min)	Y (cm)
6	2.2	2	0.12
7	2.85	3	0.25
9	3.5	5	0.5
11	4.1	10	1.27
12	4.5	14	1.81
13	5.0	18	2.22
14	5.3	21	2.47
15	5.8	26	3.23
17	6.7	30	3.74
		47	5.33
		60	6.85
		71	7.87

Data represent mean of 3 observations.

Since the surface of the test area was not completely level, and the water head measurements were done primarily in the low area, it was possible for the maximum Y readings to be higher than the mean amount of water applied, as in the case of the saturated application which was equivalent to a mean value of 6.2 cm.

According to the Soil Conservation Service permeability classification (US EPA 1977), the saturated infiltration rate at this site (6 to 7 cm hr^{-1}) corresponds to the moderately rapid class (Fig. 35).

Clarence Cannon Dam site

The preparation of site 12 required approximately the same effort as Apple Valley. At site 11, where a 3-m diameter area and only one tensiometer row were used (U.S. Army Corps of Engineers, in press), the berm installation effort was reduced to less than 2 man-hours, and the tensiometer installation to less than 1 man-hour.

At site 12 the first application was 3.2 cm of water. The second application, 6.5 cm of water, was done 2 hr after the first. Because of a low permeability layer below 30 cm, only the soil above that depth became saturated prior to the second application.

The soil tension data for the two applications at site 12 are listed in Table 4. It appears that the tensiometers at the 61- to 107-cm depths had not reached equilibrium prior to application. There is no other obvious cause for the soil tension to increase after water application. The general trend of the soil tension with time is shown in Figure 16a.

The dry density, gravimetric and volumetric soil data for site 12 are listed in Table 5 and plotted in Figures 17 and 18. The general trend of the volumetric water content with time is compared with that of soil tension in Figure 16b.

Curiously, the same problem exists here as at Apple Valley: the water content in the soil profile 2 days after application is higher than that after 1 day (mean difference approximately 2%). The increase in the 15- to 85-cm depth range does not correspond to the slight decrease in water content in the top 15 cm (Fig. 17). The problem of variations in the soil profile (and therefore an insufficient sample number) was apparently present also at this test site.

Only one water application (6.5 cm) was done at site 11. Saturation of the top 30 cm of soil was reached after approximately 0.5 hr. Judging from the soil tension data at 63 cm (Table 6), there was a layer of low permeability somewhere between 30 and 63 cm (the B horizon extended from 29 to 58 cm deep). The tension data are plotted in Figure 19.

The dry density, gravimetric and volumetric soil data for site 11 are listed in Table 7 and plotted in Figures 20 and 21. These data indicate that after 1 day the water content above 60 cm had decreased noticeably, but the tension data (Table 5) still indicate saturation after 1 day. That is, the water content data imply that after 1 day most of the applied water had drained through the low permeability layer (Fig. 20 and 21), while the soil tension data show no change between 3 hr and 1 day after the application.

Table 4. Soil tension (site 12, C. Cannon Dam).

Depth (cm):	15	30	46	61	76	91	107
Time (hr)	Tension (cm of water)						
0	240	840	710	460	410	350	30
	1st application = 3.2 cm						
0.08	220	820	705	470	440	370	60
0.17	180	830	705	475	430	380	80
0.25	60	830	705	480	470	390	95
0.33	40	830	705	490	480	400	120
0.42	30	830	705	490	490	410	130
0.50	25	830	705	500	500	410	145
0.58	20	830	705	500	510	420	160
0.67	20	830	705	510	520	425	170
0.75	15	825	705	515	525	430	180
0.83	10	820	705	530	530	430	200
0.92	10	815	705	530	535	440	205
1.0	10	800	705	540	540	440	220
1.17	10	780	705	560	550	450	230
1.25	10	765	705	560	550	450	240
1.3	15	730	705	560	555	460	250
1.4	20	700	705	565	555	460	255
1.75	15	530	700	580	560	460	280
	2nd application = 6.5 cm						
2.0	10	200	700	580	570	465	300
2.25	10	70	700	585	570	465	305
2.5	10	65	700	595	585	465	315
2.75	10	55	700	600	580	465	330
3.0	0	40	695	620	600	485	350
3.25	5	40	695	620	600	485	350
3.5	0	50	695	620	600	485	355
3.75	5	45	680	630	595	495	370
4.0	5	45	680	635	600	490	370
4.25	5	45	680	640	600	490	375
4.5	5	50	680	640	610	490	390
5.0	5	50	680	640	610	490	390
6.0	0	30	630	620	590	480	400
6.5	0	20	630	630	590	480	400
7.0	0	20	620	630	590	470	420
10.5	0	20	600	640	595	470	420
	Rain during night						
1 day	0	10	30	650	370	550	580
1.3 days	0	0	0	520	60	510	580
2 days	0	20	10	260	30	570	630
2.2 days	20	25	20	145	50	520	590

Tension data represent mean of 3 observations.

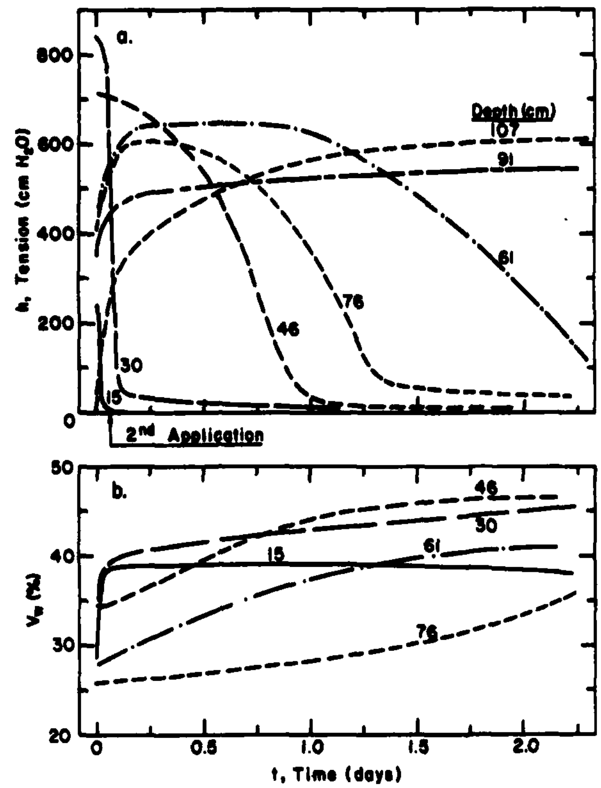


Figure 16. General trends of soil tension and volumetric water content vs time (site 12, C. Cannon Dam).

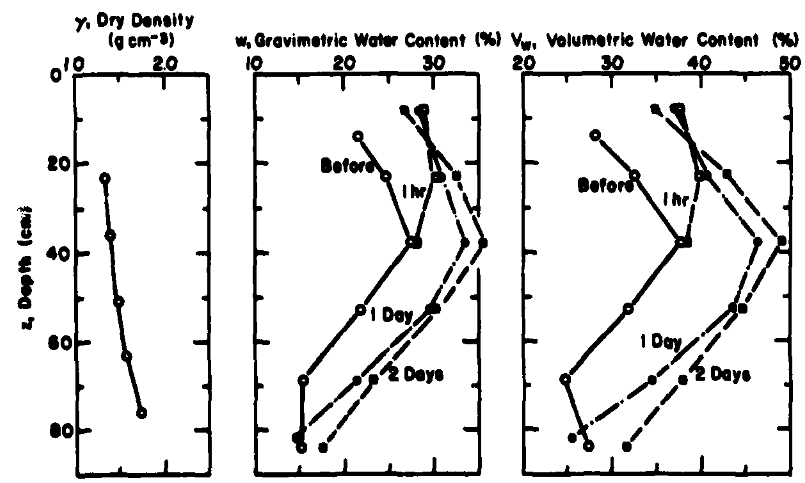


Figure 17. Soil density and water content vs depth (site 12, C. Cannon Dam).

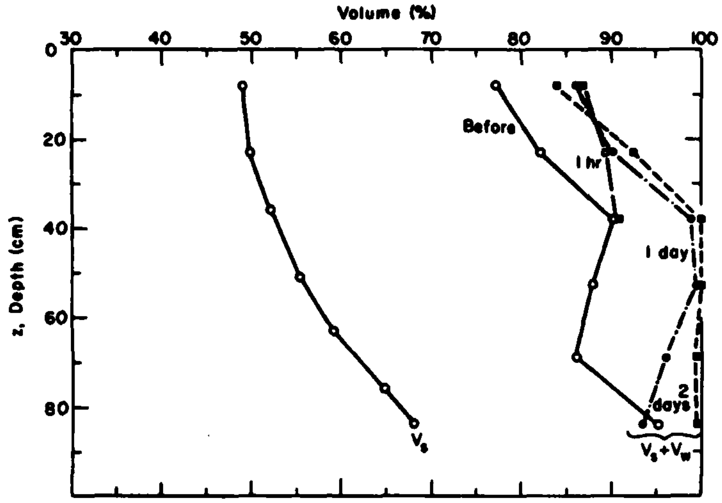


Figure 18. Volumetric composition of soil (site 12, C. Cannon Dam).

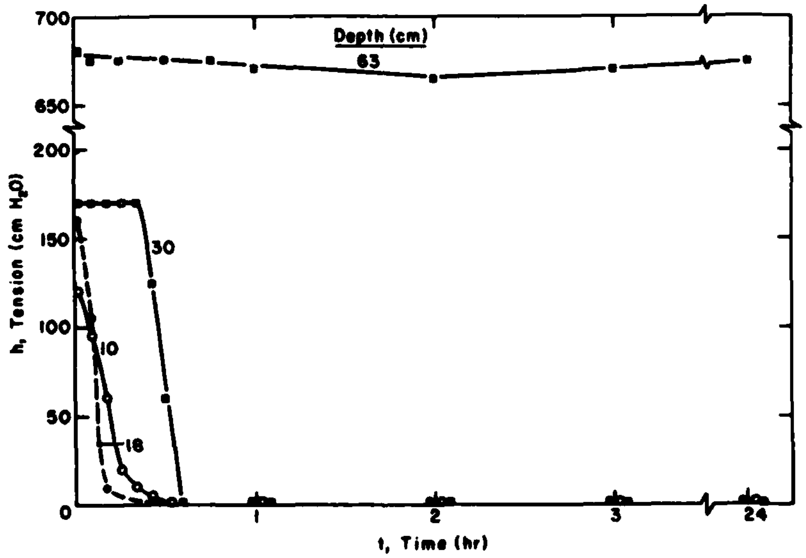


Figure 19. Soil tension vs time at various depths (site 11, C. Cannon Dam).

The cumulative intake Y vs time t data for site 11 and for the second application at site 12 are listed in Table 8 and plotted in Figure 22 on arithmetic scales. A pit, 1 m square and 40 cm deep, was excavated near site 11 and filled with 3 cm of water to observe the infiltration rate below the 40-cm depth. These data are also plotted in Figure 22. The site 12 data for the entire 8.5 hr observation period are shown in Figure 23.

Table 5. Volumetric composition of soil (site 12, C. Cannon Dam).

Depth z (cm)	Density γ (g cm^{-3})	Gravimetric w (%)	Volumetric V_w (%)	Volumetric V_s (%) (G_s = 2.65)	Volumetric $V_w + V_s$ (%)
		Water Content			
		Before application			
8	~1.3	21.6	28.1	49.1	77.2
23	1.32	24.6	32.5	49.7	82.2
38	1.38	27.4	37.8	52.5	90.3
53	1.47	21.7	31.9	56.0	87.9
69	1.62	15.2	24.6	61.5	86.1
84	~1.8	15.1	27.2	67.9	95.1
		1st application = 3.2 cm			
		1 hr after 1st application			
8		29.0	37.7	49.1	86.8
23		30.1	39.7	49.7	89.4
38		27.7	38.2	52.5	90.7
53		-			
69		-			
84		-			
		2nd application = 6.5 cm (2 hrs after 1st application)			
		1 day after applications *			
8		28.4	36.9	49.1	86.0
23		30.7	40.6	49.7	90.3
38		33.5	46.3	52.5	98.8
53		29.6	43.6	56.0	99.6
69		21.3	34.5	61.5	96.0
82		14.5	25.5	67.9	93.4
		After 2 days *			
8		26.8	34.8	49.1	83.9
23		32.4	42.8	49.7	92.5
38		35.5	49.0	52.5	~100
53		30.3	44.6	56.0	~100
69		23.3	37.8	61.5	99.3
84		17.5	31.5	67.9	99.4

* One and two day data represent mean of 2 samples.

Table 6. Soil tension (site 11, C. Cannon Dam).

Depth (cm):	10	18	30	63	76
Time (hr)	Tension (cm of water)				
0	120	160	170	680	145
	Application = 6.5 cm				
0.08	95	105	170	675	145
0.17	60	10	170	675	140
0.25	20	0	170	675	145
0.33	10	0	170	675	-
0.42	5	0	125	675	-
0.50	0	0	60	675	-
0.58	0	0	0	670	-
0.67	0	0	0	670	-
0.75	0	0	0	675	-
0.83	0	0	0	675	-
0.92	0	0	0	675	-
1.0	0	0	0	670	-
2.0	0	0	0	665	-
3.0	0	0	0	670	-
1 day	0	0	0	675	-

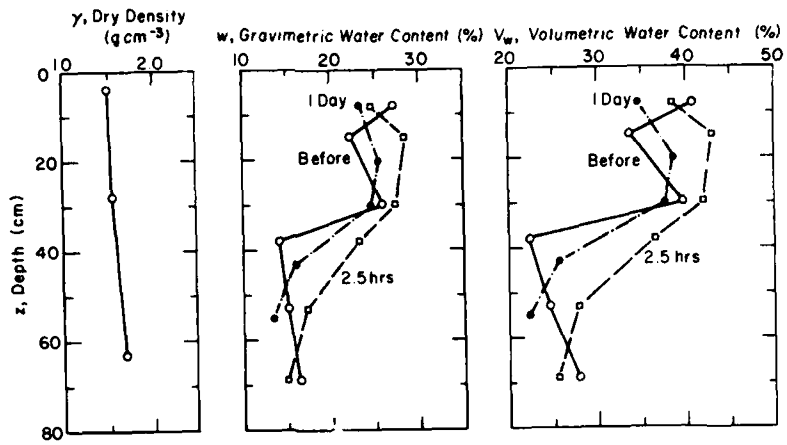


Figure 20. Soil density and water content vs depth (site 11, C. Cannon Dam).

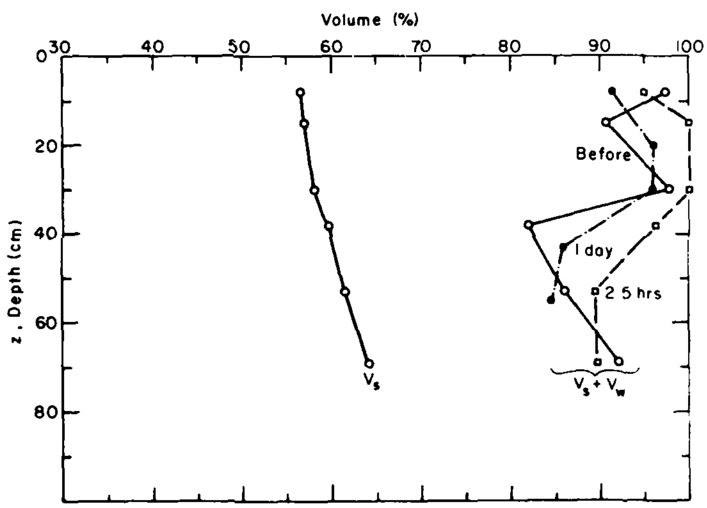


Figure 21. Volumetric composition of soil (site 11, C. Cannon Dam).

The same data, except for the pit, are shown on a log-log plot in Figure 24. There is an evident break in the site 12 log Y vs log t relationship at approximately 1 hr, which corresponds to the time when saturation was reached in the top 15 or 20 cm, and a nearly saturated condition was reached at the 30 to 35 cm depth.

A similar case exists for site 11. Saturation in the top 30 or 40 cm was reached in approximately 0.5 hr, which corresponds to a noticeable break in the log Y vs log t relationship in Figure 24. Therefore, the solid lines in Figure 24 represent the saturated condition and the dashed lines an unsaturated condition.

Table 7. Volumetric composition of soil (site 11, C. Cannon Dam).

Depth z (cm)	Density γ (g cm^{-3})	Gravimetric w (%) Water Content	Volumetric V_w (%)	Volumetric V_s (%) (G_s = 2.65)	Volumetric $V_w + V_s$ (%)
		Before application			
8	1.50	27.2	40.8	56.6	97.4
15	1.51	22.3	33.7	57.0	90.7
30	1.54	25.8	39.7	58.1	97.8
38	1.58	14.1	22.3	59.6	81.9
53	1.63	15.1	24.6	61.5	96.1
69	~ 1.7	16.4	27.9	64.2	92.1
		Application = 6.5 cm			
		2.5 hrs after application			
8	1.50	25.6	38.4	56.6	95.0
15	1.51	28.4	42.9	57.0	99.9
30	1.54	27.3	42.0	58.1	~ 100
38	1.58	23.1	36.5	59.6	96.1
53	1.63	17.2	28.0	61.5	89.5
69	~ 1.7	15.0	25.5	64.2	89.7
		After 1 day			
8	1.50	23.2	34.8	56.6	91.4
20	1.52	25.4	38.6	57.4	96.0
30	1.54	24.5	37.7	58.1	95.8
43	1.60	16.0	25.6	60.4	86.0
55	1.65	13.5	22.3	62.3	84.6

Table 8. Cumulative intake (C. Cannon Dam).

Site 12 2nd Application		Site 11		Pit at Site 11 (Surface at 40 cm)	
Time (hr)	Y* (cm)	Time (hr)	Y (cm)	Time (hr)	Y (cm)
0.25	0.75	0.08	0.5	0.25	1.3
0.5	1.0	0.17	0.8	0.5	1.5
0.75	1.45	0.25	1.0	0.75	1.6
1.0	1.9	0.33	1.4	1.0	2.0
1.25	2.1	0.42	1.7	1.25	2.4
1.5	2.25	0.50	1.9	1.5	2.5
1.75	2.4	0.58	2.0	1.75	2.6
2.0	2.45	0.67	2.1	2.0	2.7
2.25	2.75	0.75	2.2	2.25	2.9
2.5	2.85	0.83	2.4	2.5	2.9
2.75	2.9	0.92	2.7		
3.0	2.95	1	2.9		
3.5	3.05	2	4.0		
4.0	3.35				
4.5	3.65				
5.0	3.75				
8.5	4.75				

*Data represent mean of 2 observations

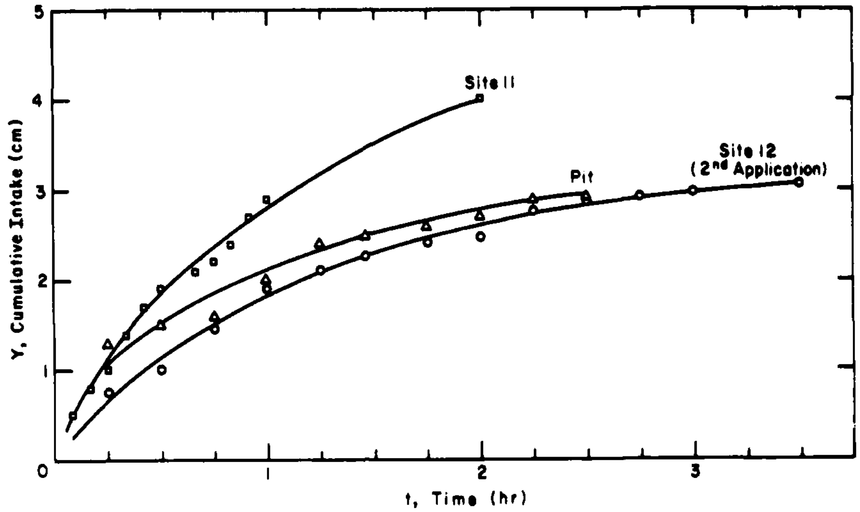


Figure 22. Cumulative intake vs time (C. Cannon Dam).

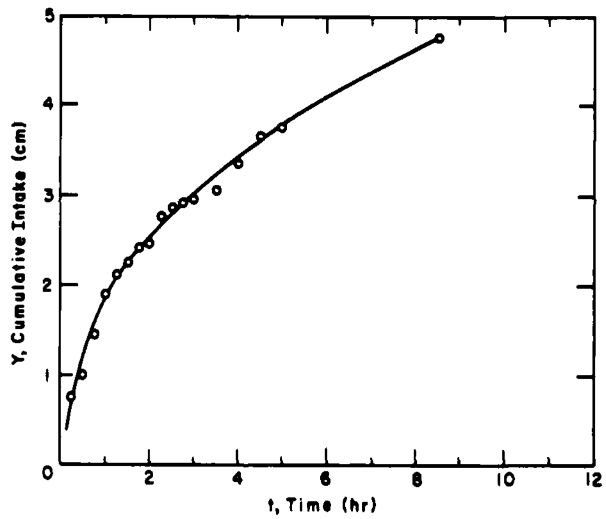


Figure 23. Cumulative intake vs time (2nd application) (C. Cannon Dam).

The expressions for the cumulative intake (from Fig. 24) and the computed infiltration rate for the saturated condition are:

Site 12 $\quad Y = 1.9\ t^{0.42}$ (cm) ($t > 1$ hr)

or $\quad Y = 0.75\ t^{0.42}$ (in.)

$\quad I = 0.8\ t^{-0.58}$ (cm hr^{-1})

or $\quad I = 0.31\ t^{-0.58}$ (in. hr^{-1})

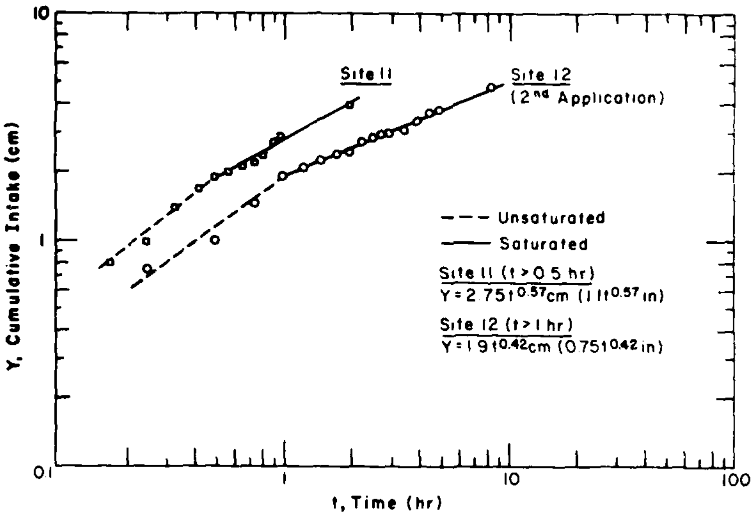


Figure 24. Cumulative intake vs time (log-log) (C. Cannon Dam).

Site 11 $\quad Y = 2.75\ t^{0.57}$ (cm) $\quad (t > 0.5$ hr)

or $\quad Y = 1.1\ t^{0.57}$ (in.)

$I = 1.6\ t^{-0.43}$ (cm hr^{-1})

or $\quad I = 0.63\ t^{-0.43}$ (in. hr^{-1})

Figure 25 shows the interpolated I values (obtained by measuring the slope of the tangent to the Y vs t curves, drawn by eye, in Fig. 22 and 23) vs time on a log-log plot. The resulting expressions are:

Site 12 $\quad I = t^{-0.65}$ (cm hr^{-1})

Site 11 $\quad I = 1.6\ t^{-0.53}$ (cm hr^{-1})

These expressions are slightly different from those obtained by computing I from the Y vs t relationships.

According to the Soil Conservation Service permeability classification (U.S. EPA 1977), the saturated infiltration rate at site 12 (0.2 to 0.8 cm hr^{-1}) is in the slow to moderately slow range and at site 11 (1 to 2 cm hr^{-1}) in the moderately slow to moderate range (Fig. 35).

Deer Creek site

The infiltration test conducted at this site is discussed in detail in another report dealing with the hydraulic characteristics of the Deer Creek Lake land treatment site (Abele et al. in press), but the data are included here for comparison.

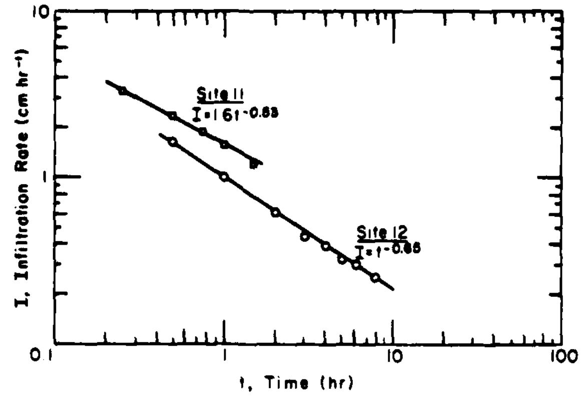


Figure 25. Infiltration rate vs time
(interpolated from Y vs t curves)
(C. Cannon Dam).

The site preparation required approximately the same effort as that at Apple Valley: 4 man-hours for berm installation, 2 man-hours for tensiometer installation, and 1 to 2 man-hours for miscellaneous tasks.

The first application was 2.5 cm of water. The second application was done after 3.3 hr when the soil was almost completely saturated.

The soil tension data are listed in Table 9 and plotted in Figure 26. The soil density, initial water content and volumetric composition data are listed in Table 10 and plotted in Figures 27 and 28.

The cumulative intake vs time data for both the unsaturated and saturated soil conditions during the first hour after application are plotted on arithmetic scales in Figure 29 (Table 11).

For the unsaturated condition, there is an apparent break in the Y vs t line at some time between 20 and 30 min, indicating a variable infiltration rate for the 1-hr period (which was the time required for the 2.5 cm of water to enter the soil).

For the saturated condition, the cumulative intake was relatively constant for the first hour (Fig. 29), but thereafter the intake rate decreased gradually with time (Fig. 30).

When plotted on a log-log plot (Fig. 31), the Y vs t data for the unsaturated condition follow an irregular, curvilinear pattern, as was already implied in Figure 29. The straight lines shown in Figure 31 for both the unsaturated and saturated conditions represent the best fit lines estimated by eye.

The expressions for the cumulative intake (from Fig. 31) and the computed infiltration rate are:

Table 9. Soil tension (Deer Creek).

Depth (cm):	8	15	30	61	86
Time	Tension (cm of water)				
0	70	55	130	30	20
	1st application = 2.5 cm				
3 min	35	55	120	20	10
5 min	25	50	120	15	0
11 min	5	35	125	10	0
15 min	5	30	120	10	0
20 min	5	20	110	5	0
30 min	5	10	105	0	0
40 min	5	5	100	0	0
50 min	0	0	90	0	0
1.0 hr	0	5	80	0	0
1.2 hr	0	5	60	0	0
1.5 hr	0	5	50	0	0
1.7 hr	5	5	45	0	0
2.0 hr	5	5	25	0	0
2.2 hr	5	5	20	0	0
2.4 hr	5	5	20	0	0
2.6 hr	5	5	20	0	0
2.9 hr	5	10	20	0	0
3.1 hr	10	10	20	0	0
	2nd application = 8.5 cm				
1 hr	0	0	0	0	0

Tension data represent mean of 3 observations.

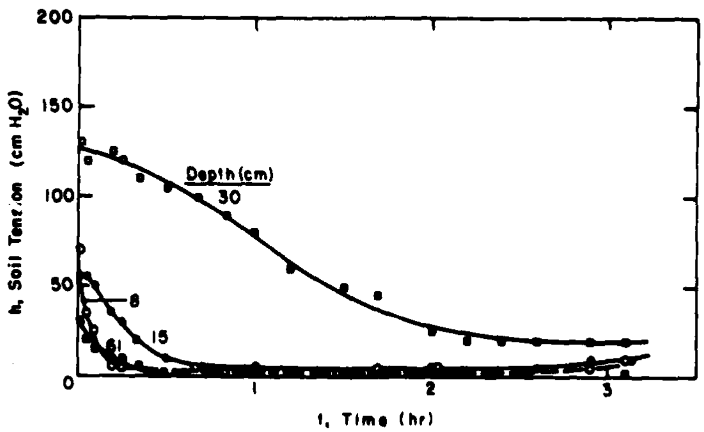


Figure 26. Soil tension vs time at various depths (unsaturated) (Deer Creek).

Table 10. Volumetric composition of soil (Deer Creek).

Depth z (cm)	Density γ (g cm^{-3})	Gravimetric w (%)	Volumetric V_w (%)	Volumetric V_s (%) (G_s = 2.71)	Volumetric $V_w + V_s$ (%)
		Water Content			
6	1.41	27.0	38.1	52.0	90.1
15	1.69	17.6	29.7	62.4	92.1
30	1.66	19.8	32.9	61.3	94.2
44	1.53	25.5	39.0	56.5	95.5
58	1.66	17.9	29.7	61.3	91.0

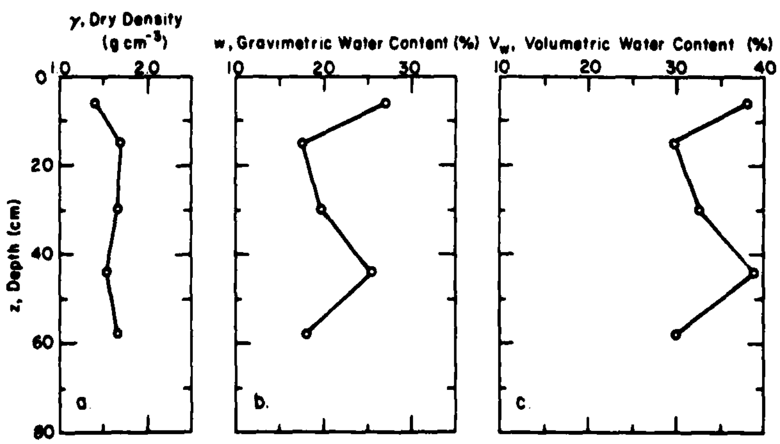


Figure 27. Soil density and water content vs depth (before application) (Deer Creek).

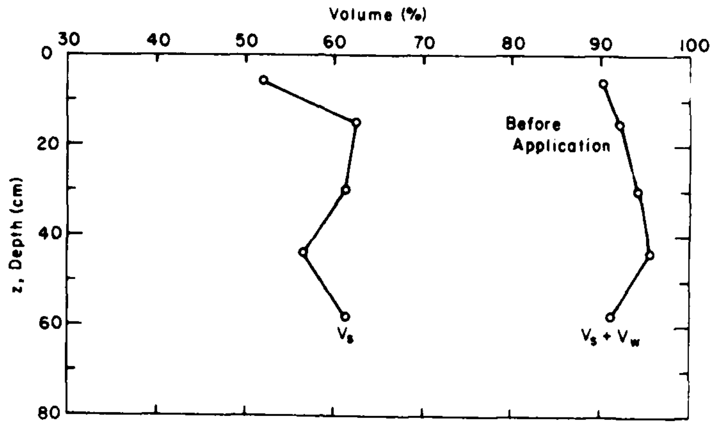


Figure 28. Volumetric composition of soil (Deer Creek).

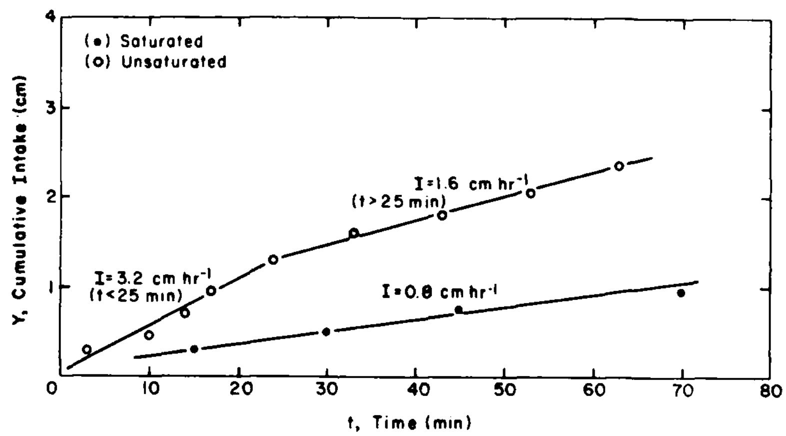


Figure 29. Cumulative intake vs time (Deer Creek).

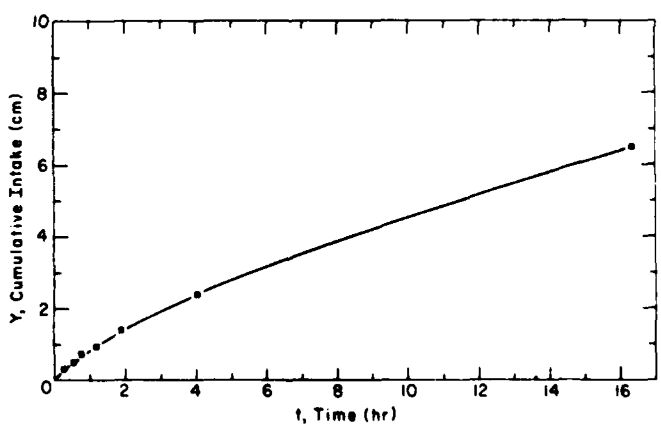


Figure 30. Cumulative intake vs time (saturated) (Deer Creek).

Table 11. Cumulative intake and incremental infiltration rate (Deer Creek).

Time (hr)	Intake Y (cm)	ΔY (cm)	Δt (hr)	Rate I (cm hr^{-1})	t (hr)
		Unsaturated condition			
0	0				
		0.3	0.05	6.0	0.025
0.05	0.3				
		0.15	0.12	1.25	0.11
0.17	0.45				
		0.25	0.06	4.17	0.20
0.23	0.7				
		0.25	0.05	5.0	0.255
0.28	0.95				
		0.35	0.12	2.92	0.34
0.40	1.3				
		0.3	0.15	2.0	0.475
0.55	1.6				
		0.2	0.17	1.18	0.635
0.72	1.8				
		0.25	0.16	1.56	0.80
0.88	2.05				
		0.3	0.17	1.76	0.965
1.05	2.35				
		Saturated condition			
0	0				
		0.3	0.25	1.2	0.13
0.25	0.3				
		0.2	0.25	0.8	0.38
0.5	0.5				
		0.25	0.25	1.0	0.63
0.75	0.75				
		0.2	0.45	0.44	0.98
1.2	0.95				
		0.45	0.7	0.64	1.55
1.9	1.4				
		1.0	2.1	0.48	2.95
4.0	2.4				
		4.1	12.3	0.33	10.15
16.3	6.5				

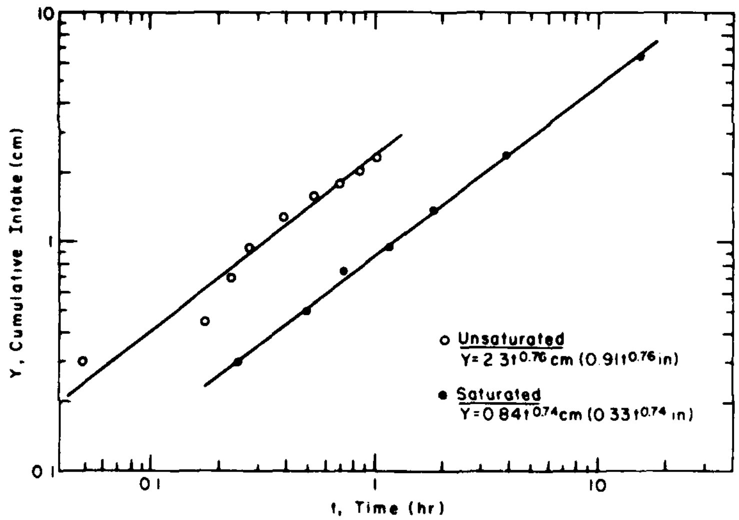


Figure 31. Cumulative intake vs time (log-log) (Deer Creek).

Unsaturated condition

$$Y = 2.3\ t^{0.76}\ \text{(cm)}$$

$$\text{or}\quad Y = 0.91\ t^{0.76}\ \text{(in.)}$$

$$(t = \text{hr})$$

$$I = 1.75\ t^{-0.24}\ (\text{cm hr}^{-1})$$

$$\text{or}\quad I = 0.69\ t^{-0.24}\ (\text{in. hr}^{-1})$$

Saturated condition

$$Y = 0.84\ t^{0.74}\ \text{(cm)}$$

$$\text{or}\quad Y = 0.33\ t^{0.74}\ \text{(in.)}$$

$$I = 0.62\ t^{-0.26}\ (\text{cm hr}^{-1})$$

$$\text{or}\quad I = 0.24\ t^{-0.26}\ (\text{in. hr}^{-1})$$

The slopes of the Y vs t, and therefore of the I vs t lines, are practically the same for both the unsaturated and saturated soil conditions.

The infiltration rate can also be calculated from the individual field measurements (Table 11), or obtained from the slope of the Y vs t lines in Figure 29 and from the slope of the tangent to the curve at any t value in Figure 30. The results of this method for the saturated condition are plotted in Figure 32 (log-log plot). The agreement between the calculated infiltration rate and that determined from the incremental measurements and interpolated values (Fig. 32) is very close:

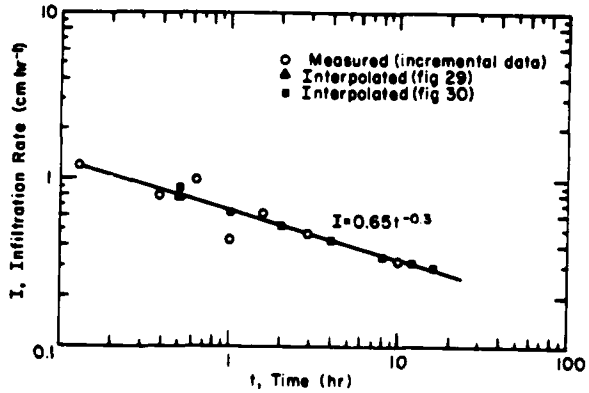


Figure 32. Infiltration rate vs time (saturated) (Deer Creek).

Calculated from log Y vs log t relationship

$$I = 0.65\ t^{-0.26}\ (\text{cm hr}^{-1})$$

Determined from best fit line for incremental values

$$I = 0.65\ t^{-0.3}\ (\text{cm hr}^{-1})$$

It should be noted that the cumulative intake and the infiltration rate for an unsaturated condition will vary, depending on the soil water content or the degree of saturation prior to the water application. The Y and I values shown here are applicable only to that particular soil water content condition and the degree of saturation at the time of the test.

According to the USDA-SCS permeability classification for saturated soils (U.S. EPA 1977), the soil permeability at this site corresponds to a range of moderately slow (0.6 cm hr^{-1} at 1 hr) to slow (0.3 cm hr^{-1} after 12 hrs) (Fig. 35).

SUMMARY AND CONCLUSIONS

The use of a large-scale, in situ infiltration test appears to be a reliable method for determining the realistic soil infiltration rates required for the design of land treatment facilities. A 6.1-m (20-ft) diameter area with a seal around the periphery of the test surface was used for three tests, and a 3-m (10-ft) diameter area was used for one test. The effort required for site preparation (layout, berm and tensiometer installation) is approximately 8 man-hours for the 6.1-m (20-ft) diameter area, and 3 to 4 man-hours for the 3-m (10-ft) diameter area.

It is felt that the smaller, 3-m diameter test area is large enough to provide representative and reliable infiltration rate data. The site preparation effort is reduced to one-half and the amount of water to one-quarter of that required for the 6.1-m diameter area.

Tensiometers are recommended for monitoring the relative degree of saturation of the soil during and after the water application. The soil density and initial water content profile should be determined from soil cores prior to the test. These data are useful for identifying the soil profile characteristics and for interpretation of the test results. However, monitoring the water content or saturation with soil samples is neither convenient nor possible while free water remains on the soil surface.

The cumulative intake vs time relationships for the saturated soil condition at the various test sites are compared on an arithmetic plot in Figure 33 and on a log-log plot in Figure 34. The saturated infiltration rates are summarized in Table 12, and their variations with time are compared in Figure 35.

The saturated infiltration rate at Apple Valley is relatively constant and, according to the SCS classification, is moderately rapid.

The saturated infiltration rates at the Clarence Cannon Dam sites decrease noticeably with time, most likely because of the low permeability layer in the lower part of the B horizon. The rate values at site 12 range from moderately slow to slow and at site 11 from moderate to moderately slow.

At Deer Creek, the saturated infiltration rate ranges from moderately slow to slow. The infiltration rate decreases with time but at a lower rate than those at Clarence Cannon Dam.

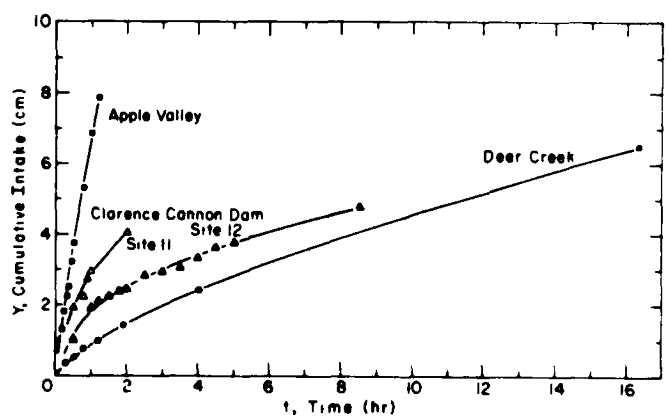


Figure 33. Summary of cumulative intake vs time (Deer Creek).

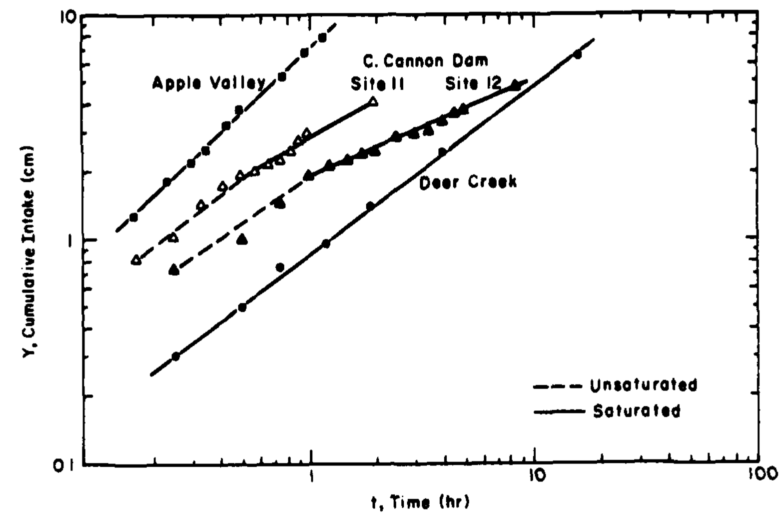


Figure 34. Summary of cumulative intake vs time (log-log).

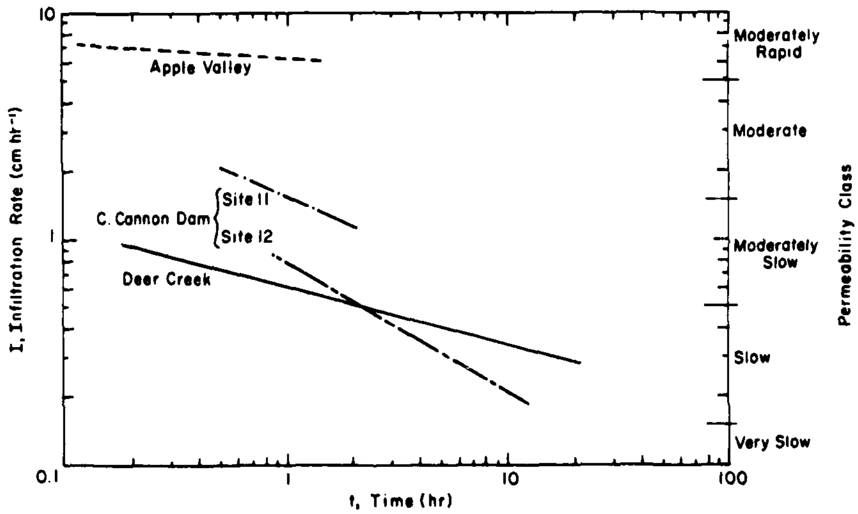


Figure 35. Summary of computed infiltration rate vs time (saturated).

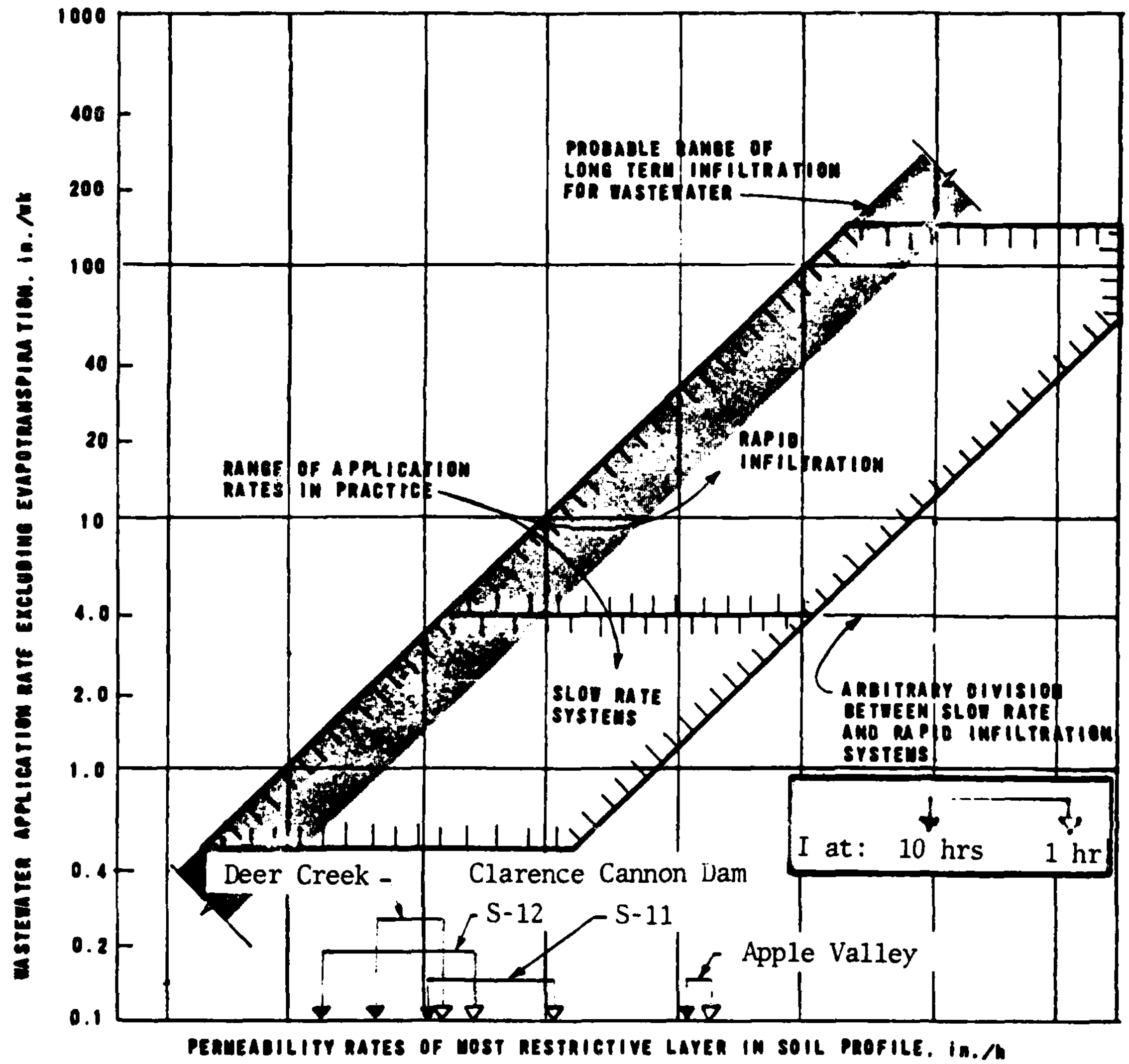
Figure 36 (reproduced from Fig. 3-3 in EPA/CoE Manual 1977) shows the estimated amount of wastewater that can be applied per week as a function of soil permeability (infiltration rate). The infiltration rates at 1 and 10 hr after the start of the saturated infiltration test at each test location are superimposed on the figure (for the Apple Valley and Clarence Cannon Dam site 11, the 10-hr values have been extrapolated; see Fig. 35).

The results from the infiltration tests indicate that the soil at the Apple Valley site would be capable of accepting approximately 50 to 100 cm (10 to 40 in.) of wastewater per week (Fig. 36) and would, therefore, be suitable for rapid infiltration.

The Clarence Cannon Dam site 12 would be suitable for slow infiltration, in the 2.5 to 10 cm (1 to 4 in.) per week range. Site 11, being more permeable than site 12, could easily accept 10 cm (4 in.) per week.

Table 12. Summary of infiltration rates (for saturated soil conditions).

Location	Infiltration rate		I at t = 1 hr		I at t = 10 hr		USDA-SCS Classification
	$cm\ hr^{-1}$	$in.\ hr^{-1}$	$cm\ hr^{-1}$	$in.\ hr^{-1}$	$cm\ hr^{-1}$	$in.\ hr^{-1}$	
Apple Valley	$I = 6.3\ t^{-0.07}$	$I = 2.5\ t^{-0.07}$	6.3	2.5	5.4	2.1	Moderately rapid
Clarence Cannon Dam							
site 12	$I = 0.8\ t^{-0.58}$	$I = 0.31\ t^{-0.58}$	0.8	0.31	0.21	0.08	Moderately slow to slow
site 11	$I = 1.6\ t^{-0.43}$	$I = 0.63\ t^{-0.43}$	1.6	0.63	0.59	0.23	Moderate to moderately slow
Deer Creek	$I = 0.62\ t^{-0.26}$	$I = 0.24\ t^{-0.26}$	0.62	0.24	0.34	0.13	Moderately slow to slow



PERMEABILITY,* SOIL CONSERVATION SERVICE DESCRIPTIVE TERMS						
VERY SLOW	SLOW	MODERATELY SLOW	MODERATE	MODERATELY RAPID	RAPID	VERY RAPID
< 0.06	0.06–0.20	0.20–0.60	0.60–2.0	2.0–6.0	6.0–20.0	> 20.0

* MEASURED WITH CLEAR WATER

1 in./wk = 2.54 cm/wk

Figure 36. Design criteria for wastewater application vs soil permeability.

The present application rate at Deer Creek is 2.5 cm (1 in.) per week. The test data indicate that, if necessary, the rate could be increased to at least twice and as much as four times the present rate. The results of the tests at Deer Creek are discussed in more detail by Abele et al. (in press).

LITERATURE CITED

Abele, G., H.L. McKim and B.E. Brockett (1979) Mass water balance during spray irrigation with wastewater at Deer Creek Lake land treatment site. U.S. Army Cold Regions Research and Engineering Laboratory Special Report 79-29.

Abele, G., H.L. McKim, D.M. Caswell and B.E. Brockett (in press) Hydraulic characteristics of Deer Creek Lake land treatement site during wastewater application. CRREL Special Report.

Haise, H.R. et al. (1956) The use of cylinder infiltrometers to determine the intake characteristics of irrigated soils. U.S. Department of Agriculture, ARS 41-7.

U.S. Army Corps of Engineers (in press) Simplified field procedures for determining vertical moisture flow rates in medium to fine textured soils. CRREL Engineer Technical Letter.

U.S. Environmental Protection Agency (1977) Process design manual for land treatment of municipal wastewater. EPA 625/1-77-008 (COE EM1110-1-501), p. 3-7.

APPENDIX A: COMMENTS ON ARS 41-7, "THE USE OF CYLINDER INFILTROMETERS TO DETERMINE THE INTAKE CHARACTERISTICS OF IRRIGATED SOILS", 1956.

In Figure 4 (p. 9) of ARS 41-7 (reproduced here as Fig. A1), which illustrates the plotting of accumulated intake data and the computation of the expressions for intake D and intake rate I, the units specified for the equations for I are in terms of inches per hour, but the actual numerical values to be used for time T are in terms of minutes.

Specifically, in an equation such as

$$I = 5.4\ T^{-0.40}\ \text{(in./hr)}$$

it would be natural to assume that (in accordance with standard mathematical convention), if the units indicated for the I are in terms of inches per hour, then the term T in the equation is also in terms of hours and the constant C indicates the intercept on the y-axis at T = 1 hr. In this example that is not so. The term T is in minutes, and the constant C = 5.4 denotes the intercept at T = 1 min, although the designated units for the numerical value of I is shown in terms of inches per hour. This type of mixing of units can be confusing.

If it is decided that the units for the intake rate are to be in terms of inches per hour, then the term T in the equations

$$D = CT^{n}$$

$$I = CnT^{n-1}$$

$$\text{and } I(\text{ave}) = CT^{n-1}$$

has to be in terms of hours, and the constant C has to represent the intercept at T = 1 hr, in order for the equations to be mathematically compatible with the specified units.

Multiplying the equations (for I) by 60, as shown on the graph, gives the correct numerical values for I, but it does not really eliminate the potential confusion of whether T is minutes or hours. A typical example of this confusion is illustrated in the instruction pamphlet itself. In the second sentence in paragraph 4, above the graph, the statement "... time T (expressed in hours)," could mislead one to assume that in the equation I Ave = 9.0 $T^{-0.40}$, shown on the graph, the term T is also in hours, which is not the case at all.

The proper equations for the data shown in the graph are

$$D = 1.75\ T^{0.60}\ \text{(in.)}$$

$$I = 1.05\ T^{-0.40}\ \text{(in./hr)}$$

$$I\ (\text{ave}) = 1.75\ T^{-0.40}\ \text{(in./hr)}$$

$$(T = \text{hr})$$

and in the general equations, shown in the lower right corner of the graph, the constant 60 should be deleted. For clarity, it would also be desirable to add to the x-axis a scale in hours.

Furthermore, it may be desirable to update the ARS 41-7 by converting to the metric system, i.e., expressing D in cm and I in cm hr^{-1}.

COMPUTING and PLOTTING DATA

1. Compute the average accumulated intake for each period of elapsed time. See the last column of the example shown on Figure 1.

2. Plot points of accumulated intake against elapsed time. Draw best-fit curve through the plotted points. Rectangular coordinate or log paper may be used. These curves often will be straight lines on log paper. Figure 3 shows the data from Figure 1 plotted on rectangular coordinate paper and Figure 4 shows these same data plotted on log paper.

3. Compute and plot the instantaneous intake rate curve from the accumulated intake curve, as drawn in 2 above. See Figures 3 and 4. This procedure will provide an intake rate curve that matches the accumulated intake curve. Computation of intake rates from the original field data usually results in unsatisfactory rate cirves.

4. If desired, compute and plot average intake rate curve. The average intake rate is the accumulated intake (inches) to any time T divided by the time T (expressed in hours). Sample average intake rate curves are shown in Figures 3 and 4.

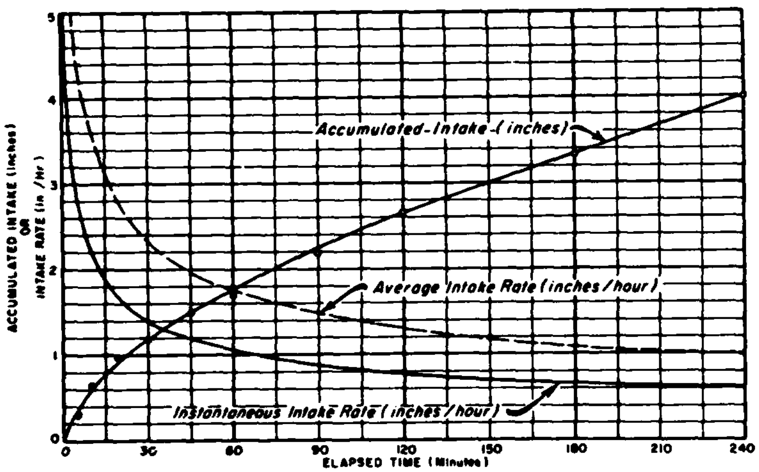


Fig. 3: Sample Intake Curves

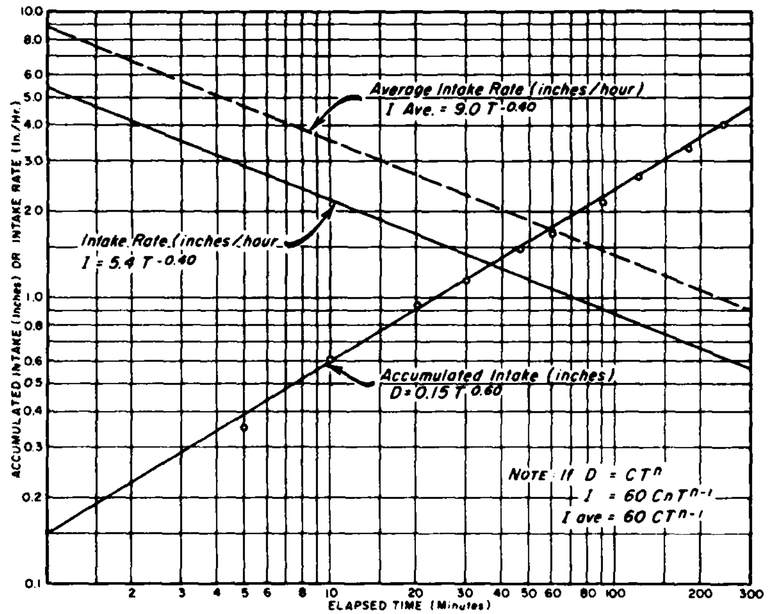


Fig. 4: Sample Intake Curves

Figure A1. Sample intake curves, ARS 41-7.

*US GOVERNMENT PRINTING OFFICE: 1980—700-341/232